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SCS-CN METHOD OF RUNOFF ESTIMATION USING REMOTE SENSING AND GIS TOOLS FOR THE HIREHALLA WATERSHED OF KARNATAKA, INDIA

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ABSRACT

A watershed is a region covering all of the property which contributes runoff water into some frequent point. It's a natural physiographic or environmental entity made up of interrelated components and works. Back in India, the access to accurate info on runoff is barely accessible several selected websites. But, quickening of this pest control programme for development and conservation of natural resources management has required the runoff details. Improvements in computational power and the expanding accessibility of spatial information have made it feasible to correctly forecast the runoff. The chance of quickly mixing information of different kinds in a Geographic Information System (GIS) has resulted in considerable increase in its usage in hydrological software. This technique incorporates several crucial properties of this watershed specifically soil's permeability, land usage and antecedent soil water requirements that are taken under account. Runoff is among the key hydrologic factors utilised from the water resources management and applications preparation. Considering all of the details utilizing geospatial tools runoff or its mini- watersheds of all Hirehalla has been completed along with the close examination of these results shows that in most of the mini-watersheds, the coefficient of correlation (R2) values varied from 0.1167 into 0.8438 for the annual rain and yearly runoff connection.

KEYWORDS: Geographic Information system (GIS), Watershed, Curve Number Method & Runoff

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Original Article

1. INTRODUCTION

Estimation of surface runoff is crucial for the evaluation of water flow potential of this watershed, preparation of water conservation steps, recharging the groundwater lines, reducing the sedimentation and flood menaces downstream. Also, it's a significant and essential requirement of Integrated Watershed Management (Subramanya K. (2008)) [1]. “Many runoff simulations models, such as the Sacramento model [2], Tank model [3], HBV model [4], MIKE 11/NAM model [5,6] and Soil Conservation Service curve number (SCS-CN) method, have been proposed and applied to urban runoff prediction. Among these models, the SCS-CN is one of the most enduring methods for estimating the volume of direct surface runoff in ungauged rural catchments” [7].

Remote Sensing and GIS methods are becoming increasingly utilized for preparation, GIS particularly aid in Incorporating a variety of data collections and perform spatial analysis to decision making. GIS and remote sensing are now being employed for solving ecological issues such as degradation of soil by water, soil erosion, deforestation, changes in environmental parameters and a lot more.

“Jasrotia et al. [8] used a mathematical model to estimate rainfall, runoff in conjunction with remote sensing data and GIS using SCS CN method and runoff potential map. AshishPandey et al. [9] estimated the runoff from SCS curve number model modified for Indian condition by conventional data base and GIS for Dikrong river

basin. Amutha et al., [10] showed that estimation of runoff by SCS-CN method integrated with GIS can be used in watershed management effectively. Somashekar et al.,[11] estimated surface runoff of Hesaraghatta watershed. The analysis was carried using IRSID LISS III satellite images in the form of false color composites(FCC) using SCS curve number method and found that the runoff estimated by SCS method shown reasonable good result. Pandey and Sahu (2002)[12] inferred that the land use/land cover is an important parameter input of the SCS-CN model. Nayak and Jaiswal (2003)[13] noticed that there was a good correlation between the measured and estimated runoff depth using GIS and CN. Hence SCS-CN method was used to evaluate the runoff depth required for the estimation of sediment yield in the Hirehalla watershed".

2. SCS CURVE NUMBER METHOD

The curve number method (Soil Conservation Services, SCS, 1972) also referred to as the hydrologic soil cover complex process, is a flexible and popular process for runoff estimation. Inside this approach several significant properties of this water shed specifically land permeability, land usage and antecedent soil moisture conditions have been taken under account. To gauge the curve amount, the property use/land insure and hydrological soil group ready in IRS satellite data have been used. Excel spread sheet has been ready for the opinion of runoff utilizing SCS-CN technique.

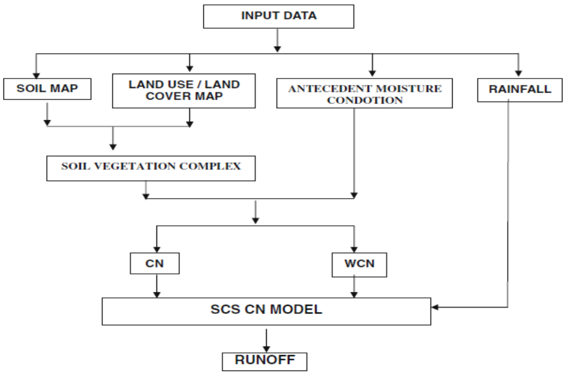

Figure 1: Methodology to Estimate Surface Runoff by SCS-CN Model.

3. RUNOFF VOLUME

Surface runoff is principally controlled by the number of rain, first abstraction and moisture retention of the ground. The SCS curve number system is based upon the water balance equation along with also two basic hypotheses that are mentioned as, ratio of the real direct runoff into the possible runoff is equivalent to the proportion of the real infiltration into the possible infiltration, and the quantity of original abstraction is a certain portion of the possible infiltration.

$$(P - I_a - Q) / S = Q / (P - I_a) \qquad (1)$$

Where: P = precipitation in millimeters ($P \geq Q$); Q = runoff in millimeters; S = potential maximum retention in millimeters; I_a = Initial Abstraction.

The second concept is that the amount of initial abstraction is some fraction of the potential maximum retention and thus expressed as:

$$I_a = \lambda S \text{ (for Indian condition } I_a = 0.3S) \qquad (2)$$

$$\text{Where, } S = 25400/CN - 254. \qquad (3)$$

Solving equation (1) and using equation (2) we have

$$Q = (P - I_a)^2 / (P - I_a + S) \tag{4}$$

For Indian condition $I_a = 0.3S$, thus equation (4) becomes:

$$Q = (P - 0.3S)^2 / (P - 0.7S) \tag{5}$$

Equation 5 is the rainfall – runoff relation, which is used in the estimation of runoff from the storm rainfall.

4. ANTECEDENT MOISTURE CONDITION

Antecedent moisture condition (AMC) refers to the water content present in the soil at a given time. It is determined by total rainfall in 5 day period preceding a storm. SCS developed three antecedent soil-moisture conditions and labeled them as I, II, III, according to soil conditions and rainfall limits for dormant and growing seasons. Classification of Antecedent Moisture Condition is shown in Table 1.

Table 1: Classification of Antecedent Moisture Conditions (AMC)

AMC Class	Description of soil condition	Total rainfall (mm) in previous five day	
		Dormant season	Growing season
I	Soils are dry but not to the wilting point; satisfactory cultivation has taken place.	< 12.7 mm	< 35.56 mm
II	Average conditions.	12.7 - 27.94 mm	35.56 - 53.34 mm
III	Heavy rainfall or light rainfall and low temperatures have occurred within last 5 days; Saturated soils	> 27.94 mm	53.34 mm

5. HYDROLOGICAL SOIL GROUP (HSG) CLASSIFICATION

SCS developed soil classification system that consists of four groups, which are identified as A, B, C, and D according to their minimum infiltration rate. Table 2 shows the hydrological soil group classification (Mc. Cuen, 1982) [14]. CN values were determined from hydrological soil group and antecedent moisture conditions of the watershed. The Curve Number values for AMC-I and AMC-II were obtained from AMC-II (Chow et al. 1988) [15] by the method of conservation. Runoff curve numbers (AMC II) for hydrologic soil cover complex are shown in the Table 3. The Figure 3 shows the hydrological soil group map of Hirehalla watershed.

Table 2: Hydrological Soil Group Classification

Soil Group	Description	Minimum Infiltration Rate (mm/hr)
A	“Soils in this group have a low runoff potential (high-infiltration rates) even when thoroughly wetted. They consist of deep excessively well drained sands or gravels. These soils have a high rate of water transmission”.	7.62–11.43
B	“Soils in this group have moderate infiltration rates when thoroughly wetted and consists chiefly of moderately deep to deep, well-drained to moderately well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission”.	3.81–7.62
C	“Soils have slow infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes the downward movement of water, or soils with moderately fine-to fine texture. These soils have a slow rate of water transmission”.	1.27–3.81

D	"Soils have a high runoff potential (very slow infiltration rates) when thoroughly wetted. These soils consist chiefly of clay soils with high swelling potential, soils with a permanent high-water table, soils with a clay layer near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission".	0–1.27

Source: (Mc. Cuen, 1982) [14]

Table 3: Runoff Curve Numbers (AMC II) for Hydrologic Soil Cover Complex

Sl No.	Land use	Hydrologic Soil Group			
		A	B	C	D
1	Agricultural land without conservation (Kharif)	72	81	88	91
2	Double crop	62	71	88	91
3	Agriculture Plantation	45	53	67	72
4	Land with scrub	36	60	73	79
5	Land without scrub (Stony waste/ rock out crops)	45	66	77	83
6	Forest (degraded)	45	66	77	83
7	Forest Plantation	25	55	70	77
8	Grass land/pasture	39	61	74	80
9	Settlement	57	72	81	86
10	Road / railway line	98	98	98	98
11	River / stream	97	97	97	97
12	Tanks without water	96	96	96	96
13	Tank with water	100	100	100	100

Source :(Chow et al. 1988) [15]

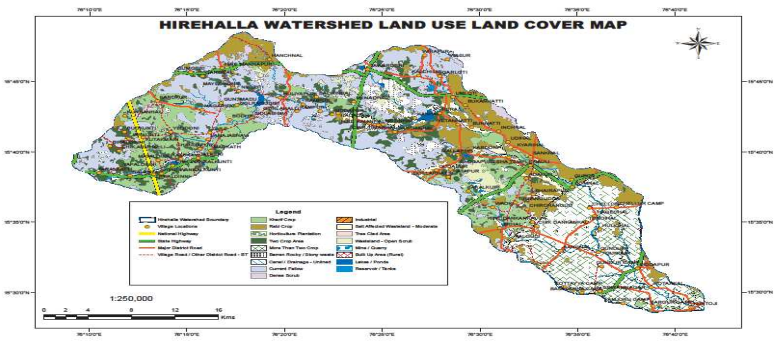

Figure 2: Land Use and Land Cover Map of Hirehalla Watershed of Koppal District.

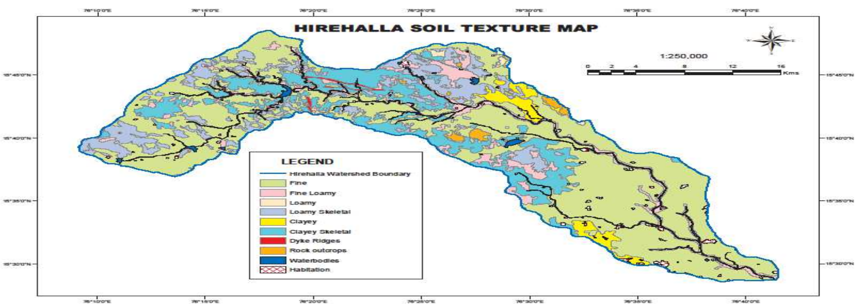

Figure 3: Soil Texture Map of Hirehalla Watershed of Koppal District.

6. APPLICATION OF REMOTE SENSING AND GIS FOR ESTIMATING RUNOFF

One of the options for use of remote sensing and GIS is to improve the estimation of watershed parameter like curve number for drainage with widely used SCS model from its spatial detailed information through land use data and digitized soil map (Sundar Kumar et al. 2010[16] and KamathArunet al.2013 [17]). In the present study, an attempt has been made to use remote sensing data with GIS system for estimating runoff depth using distributed curve number technique.

7. THIESSEN POLYGON MAP

Thiessen polygon map of the study area is depicted in Figure 4. Kushtagi, Hulihaider, Tawargeri, Navali, Kanakagiri, Siddapur and Waddarhatti rain gauge stations covered Hirehalla watershed. Thiessen polygon encloses the maximum area covered by Kushtagi station, while Karatagi rain gauge covers the least. The Thiessen polygon was used in the rainfall estimation for individual mini-watersheds. It gives the rainfall distribution over the entire watershed when the rain gauge stations were sufficiently not distributed. The mini-watershed wise distribution of different Thiessen polygon areas is presented in Table 4.

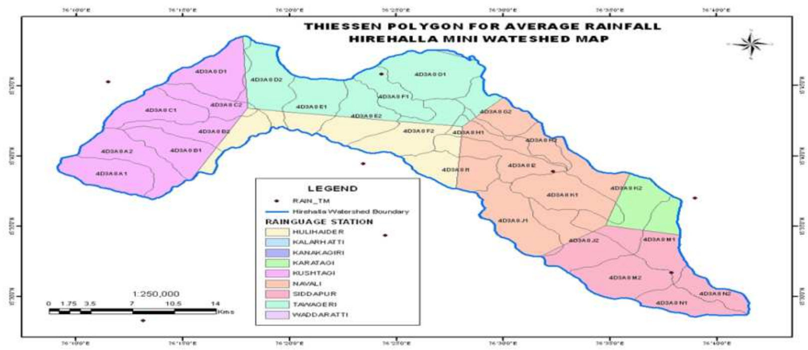

Figure 4: Thiessen Polygon for Average Annual Rainfall of Hirehalla Water Shed.

Table 4: Average Annual Rainfall (2007-2016) of Hirehalla Mini-watersheds

Sl. No.	Mini Watershed Code	Avg. Rainfall for Mini Watershed in mm
1	4D3A8A1	538.18
2	4D3A8A2	538.18
3	4D3A8B1	535.36
4	4D3A8B2	528.71
5	4D3A8C1	538.18
6	4D3A8C2	536.04
7	4D3A8D1	535.32
8	4D3A8D2	498.59
9	4D3A8E1	500.50
10	4D3A8E2	505.01
11	4D3A8F1	494.75
12	4D3A8F2	508.90
13	4D3A8G1	495.79
14	4D3A8G2	556.51
15	4D3A8H1	577.1
16	4D3A8H2	587.47
17	4D3A8I1	554.00
18	4D3A8I2	579.60
19	4D3A8J1	598.05

20	4D3A8J2	687.57
21	4D3A8K1	591.09
22	4D3A8K2	595.99
23	4D3A8M1	669.40
24	4D3A8M2	746.58
25	4D3A8N1	746.58
26	4D3A8N2	746.58

Table 5: Runoff Curve Numbers (AMC II) for Hydrologic Soil Cover Complex of Hirehalla Mini Watersheds

Sl. No.	Watershed Code	Name	Area(a) Km^2	Hydrologic Soil Group	Weighted Curve Number
1	4D3A8A1	Nalagol	27.74	C/B	87.75
2	4D3A8A2	Mataldinni	29.83	C/B	87.79
3	4D3A8B1	Yeddoni	26.96	C/B	87.68
4	4D3A8B2	Sidlabhavi	28.57	C/B	87.96
5	4D3A8C1	Nagarhal	25.64	C/B	86.65
6	4D3A8C2	Guntanmadu	16.47	C/B	89.55
7	4D3A8D1	Hiremannur	30.96	C/B/A	81.99
8	4D3A8D2	Huliyapur	32.66	C/B/A	86.29
9	4D3A8E1	Hiremukarthal	28.72	C/B	88.24
10	4D3A8E2	Menadhal	31.91	C/B/A	85.19
11	4D3A8F1	Tawargeri	19.41	D/C/B	86.76
12	4D3A8F2	Sanganhal	33.13	C/B	87.53
13	4D3A8G1	Wirapur	41.26	C/B/A	85.44
14	4D3A8G2	Bukanhatti	22.79	B/A	83.33
15	4D3A8H1	Yetanhatti	13.60	D/C/A	85.96
16	4D3A8H2	Banhatti	14.06	D/B/A	82.04
17	4D3A8I1	Gudadur	28.36	C/B	85.91
18	4D3A8I2	Nauli	26.69	C/B/A	83.88
19	4D3A8J1	Wadki	36.74	C/B/A	86.26
20	4D3A8J2	ChikDanknal	33.98	C/B/A	80.66
21	4D3A8K1	Adapur	32.12	C/B/A	80.88
22	4D3A8K2	Hulkihal	50.61	D/A	78.57
23	4D3A8M1	Siddapur	27.5	A	76.46
24	4D3A8M2	Shriram Nagar	31.56	B/A	76.93
25	4D3A8N1	Kotankal	18.68	D/A	77.75
26	4D3A8N2	Kuntoji	14.42	B/A	79.72
		Total	724.37		

8. ANNUAL RUNOFF ESTIMATION

The mini-watershed wise annual rainfall for the period of 2006 to 2015 corresponding annual runoff and runoff percentage is given in Table 5. The annual runoff varied from 0.0 mm in mini-watersheds 4D3A8G2, H1.H2, I2, J1, K1 and K2 during 2011 to 362.49 mm (37.9% of rainfall) in mini-watershed 4D3A8J2 during 2009 of the annual rainfall. The year wise average runoff yield in entire watershed for 2006-2015 is presented in the Table 6. The scrutiny of the Table 6 reveals that the annual runoff yield was in proportion to the annual rainfall.

Table 6: Mini-watershed Wise Annual Runoff for the Period of 2006–2015

MW No.	2006 Runoff (mm)	2007 Runoff (mm)	2008 Runoff (mm)	2009 Runoff (mm)	2010 Runoff (mm)	2011 Runoff (mm)	2012 Runoff (mm)	2013 Runoff (mm)	2014 Runoff (mm)	2015 Runoff (mm)	Average Runoff (mm)
4D3A8A1	30.35	239.62	163.72	346.00	102.90	16.56	55.01	79.33	162.25	112.46	130.82
4D3A8A2	30.54	240.30	164.20	346.75	103.34	16.71	55.31	79.77	162.95	112.90	131.28
4D3A8B1	30.04	238.52	162.91	344.76	102.16	16.31	54.50	78.61	161.10	111.74	130.07

4D3A8B2	31.30	250.03	166.17	349.79	105.15	17.32	56.57	81.53	165.76	114.68	133.83
4D3A8C1	25.87	223.18	151.72	327.79	92.19	13.04	47.60	68.79	145.35	101.91	119.74
4D3A8C2	39.51	271.38	186.46	381.05	124.79	24.23	70.12	100.36	195.56	133.66	152.71
4D3A8D1	13.01	169.86	110.94	262.98	59.55	4.10	25.70	36.55	92.97	69.21	84.49
4D3A8D2	4.22	28.39	3.07	17.70	7.52	10.06	6.06	51.80	57.60	46.94	23.33
4D3A8E1	83.54	321.05	208.34	277.52	185.58	26.67	43.55	151.30	207.40	164.02	166.90
4D3A8E2	3.33	24.99	2.45	110.26	5.82	7.89	4.83	44.36	50.68	42.60	29.72
4D3A8F1	69.95	294.30	190.44	257.59	159.57	29.20	35.81	138.84	186.39	145.66	150.77
4D3A8F2	5.50	33.08	4.03	127.46	9.98	13.16	8.61	61.53	67.12	52.77	38.32
4D3A8G1	59.75	273.65	175.89	241.39	139.34	17.16	30.07	129.19	169.63	130.85	136.69
4D3A8G2	8.47	93.29	39.52	174.69	5.65	0.00	2.33	3.30	0.38	0.04	32.77
4D3A8H1	14.03	114.38	49.62	196.31	8.87	0.00	4.11	5.44	1.16	0.42	39.43
4D3A8H2	8.54	84.73	35.38	165.49	4.43	0.00	1.67	2.57	0.16	0.00	30.30
4D3A8I1	3.89	27.17	2.84	115.07	6.90	9.26	5.73	49.17	55.13	45.40	32.05
4D3A8I2	9.44	97.25	41.43	178.84	6.23	0.00	2.64	3.66	0.50	0.09	34.01
4D3A8J1	14.84	117.16	50.94	199.09	9.33	0.00	4.36	5.75	1.28	0.10	40.28
4D3A8J2	0.37	97.96	62.94	362.49	164.27	2.07	29.32	87.41	25.17	33.00	86.50
4D3A8K1	5.15	77.09	32.08	157.96	3.51	0.00	1.20	2.06	0.05	0.00	27.91
4D3A8K2	3.12	66.07	26.48	144.54	2.07	0.00	0.51	1.36	0.00	0.00	24.41
4D3A8M1	0.00	74.37	47.99	329.71	134.73	0.22	17.79	71.48	13.80	20.72	71.08
4D3A8M2	0.00	76.75	49.46	333.11	137.68	0.29	18.90	73.02	14.78	21.91	72.59
4D3A8N1	0.02	81.05	52.13	339.19	143.01	0.47	20.94	75.84	16.64	24.09	75.34
4D3A8N2	0.20	92.17	59.19	354.62	156.93	1.35	26.39	83.37	22.02	29.90	82.61

9. RAINFALL–RUNOFF RELATIONSHIPS

The annual runoff yield values of the all mini-watersheds in the Hirehalla watershed during the study period of 10 years (2006-2015) were grouped into set of arrays for the each mini-watershed with the corresponding annual rainfall was used to develop the relationships. For the individual mini-watershed, the best fit lines, obtained by the least square method, show a linear correlation between annual rainfall and runoff. The close scrutiny of the table reveals that in all the mini-watershed, the coefficient of correlation (R^2) values vary from 0.1167 to 0.8438 for the annual rainfall and annual runoff relationship. It can be inferred that annual runoff yield can be predicted by the annual rainfall data with better accuracy.

Table 7: Rainfall-Runoff Relationship of Mini-Watersheds of Hirehalla for the Period 2006–2015

MW	Annual Rainfall and Annual Runoff Relationship	Correlation Coefficient
4D3A8A1	y = 0.4156x - 150.43	$R^2 = 0.7802$
4D3A8A2	y = 0.4165x - 150.61	$R^2 = 0.7809$
4D3A8B1	y = 0.4141x - 150.16	$R^2 = 0.7792$
4D3A8B2	y = 0.4239x - 153.03	$R^2 = 0.7837$
4D3A8C1	y = 0.3929x - 146.16	$R^2 = 0.7644$
4D3A8C2	y = 0.4585x - 157.58	$R^2 = 0.8000$
4D3A8D1	y = 0.3128x - 127.19	$R^2 = 0.7065$
4D3A8D2	y = 0.0365x - 1.3369	$R^2 = 0.136$
4D3A8E1	y = 0.3077x + 54.536	$R^2 = 0.2729$
4D3A8E2	y = 0.0853x - 23.975	$R^2 = 0.2557$
4D3A8F1	y = 0.2872x + 45.915	$R^2 = 0.2791$
4D3A8F2	y = 0.1003x - 24.761	$R^2 = 0.2609$
4D3A8G1	y = 0.2767x + 35.675	$R^2 = 0.2818$
4D3A8G2	y = 0.1527x - 63.284	$R^2 = 0.2831$
4D3A8H1	y = 0.4152x - 92.453	$R^2 = 0.8092$
4D3A8H2	y = 0.3393x - 77.484	$R^2 = 0.7853$
4D3A8I1	y = 0.1454x - 14.112	$R^2 = 0.3377$
4D3A8I2	y = 0.1254x - 11.762	$R^2 = 0.1167$
4D3A8J1	y = 0.4224x - 93.891	$R^2 = 0.8117$
4D3A8J2	y = 0.583x - 98.675	$R^2 = 0.5774$
4D3A8K1	y = 0.1542x - 53.58	$R^2 = 0.4194$
4D3A8K2	y = 0.2889x - 67.339	$R^2 = 0.7604$

4D3A8M1	y = 0.5309x - 97.529	R^2 = 0.5696
4D3A8M2	y = 0.4224x - 150.68	R^2 = 0.8278
4D3A8N1	y = 0.4307x - 152.33	R^2 = 0.8324
4D3A8N2	y = 0.4517x - 156.14	R^2 = 0.8438

10. RESULTS AND DISCUSSIONS

The annual rainfall of Kustagi rain gauge station ranged from 386.80mm (2006) to 997.30mm (2009), further the distribution is erratic in nature. The annual rainfall of Hulihyder rain gauge station varies between 123.6mm (2006) to 584.2mm (2009) and the trend is increasing. Rainfall distribution of Tawargere rain gauge station is varying from 285.8mm (2011) to 817.6 mm (2009). The annual rainfall of Navali, Kanakgiri, Siddapur and Waddarhatti rain gauge stations are varying from 159mm (2011) to591mm (2009),237.8mm (2011) to 844mm (2009),261.9mm (2006) to 956.4mm (2009) and 270.4mm (2006) to 1176.1mm (2009) respectively. The Thiessen polygon was used in the rainfall estimation for individual mini-watersheds. It gives the rainfall distribution over the entire watershed when the rain gauge stations were sufficiently not distributed. The annual runoff varied from 0.0 mm in mini-watersheds 4D3A8G2, H1.H2, I2, J1, K1 and K2 during 2011 to 362.49 mm (37.9% of rainfall) in mini-watershed 4D3A8J2 during 2009 of the annual rainfall. The scrutiny of the results reveals that the annual runoff yield was in proportion to the annual rainfall. Further, runoff has no consistent trend over the years. It is obvious that the years that receive higher rainfall will produce higher amount of runoff and vice-versa.

In the individual mini-watersheds, the best fit lines, obtained by the least square method, shows a linear correlation between annual rainfall and runoff yield in each case. The close scrutiny of the results tabulated (Table7) reveals that in all the mini-watersheds, the coefficient of correlation (R^2) values varied from 0.1167 to 0.8438. It can be inferred that annual runoff yield can be predicted by the annual rainfall data with better accuracy using SCS-CN method.

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Dr. C.B.Shivayogimath has been appointed as one man Expert committee by the Hon. National Green Tribunal (NGT) Southern Zone, Chennai Govt. of India.